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DEVELOPMENT OF SPIN TESTING TECHNIQUE AS A FUNCTION OF SPIN OF MODERN AIRCRAFT

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DEVELOPMENT OF SPIN TESTING TECHNIQUE AS A FUNCTION OF SPIN OF MODERN AIRCRAFT /1**

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Recent improvements in the testing technique at the vertical wind tunnel of the Lille Institute for Fluid Dynamics are discussed, followed by a review of spin classification and spin recovery. Test data of spin models, in flat, normal, inverted spins and uncontrolled dives, are extrapolated to full-scale aircraft with guidelines for setting of the control surfaces. Addition of auxiliary surfaces, such as keelsons and fairings, is evaluated in relation to more rapid recovery from spin.

1. Wind Tunnel Research on Spin Characteristics and Spin Recovery of a Given Aircraft

We will start this discussion by reviewing first the improvements made in our testing technique in the vertical wind tunnel since the paper presented at the AGARD* meeting on November 5, 1954. In 1954, we mainly outlined our classification of spin and spin recovery, demonstrated our mode of data presentation, and illustrated the discussion with a film.

The method described then is still in use and continues being highly successful. Nevertheless, within the scope of this method, we were obliged to learn how to interpret certain results of wind tunnel tests so as to better predict the results of full-scale tests.

Our classification comprises stationary spin(permanent or transient), unstable spin and recovery from spin.

In the unstable spins, we only included spins which, within a more or less long interval of time, ended in recovery from spin. However, in view of the rapid flat spins of many modern aircraft, it became necessary to account also for nonstationary spins tending to a stationary spin rather than to recovery. Thus, it was a question of defining, in addition to the stationary spin itself, the mode in which the aircraft could reach this stationary spin and even if this were possible at all. This particular point will be discussed first, with a description of how we solved the problem.

a) Rapid and Flat Spins

Until the appearance of rapid and flat spins, the model had always been

* AGARD = Advisory Group for Aeronautical Research and Development.

** Numbers given in the margin indicate pagination in the original foreign text.

launched in an attitude and with a rotation close to the stationary spin; this spin became rapidly established: In most cases, one single turn brought the model very close to a stabilized spin. /2

If this practice is to be retained for rapid flat spins, it would be necessary to impart to the model from the very beginning an attitude and a rotation far from those of incipient spin of the full-scale aircraft. In addition, one usually is quite far from these conditions since the time required for establishing this type of spin frequently is so great that, in actual flight, the final stationary spin is rarely ever attained. Consequently, to place the model immediately into its stabilized spin would mean to neglect practically the entire motion executed by the full-scale aircraft.

Since these spins take long to stabilize, the spin axis of the aircraft would have become vertical before the spin is actually stabilized. Therefore, it is completely legitimate to make tests in a free spinning tunnel in order to define the mode in which the aircraft tends toward its stabilized spin. Thus, instead of launching the model in a plane with a strong imposed rotation, we now successively launch our models in more or less nose-down attitudes at increasing rates of rotation. The next step is to observe the behavior of the model, namely to determine whether the spin flattens out or accelerates and with what rapidity these evolutions take place. In applying this method, we found that a stationary flat and rapid spin can be obtained by different means, varying with the given case:

I. under the express condition that the model, from the beginning, is launched in a flat spin with rapid rotation;

II. by a progressive development of movement, launching the model in a certain range of longitudinal angle of trim at moderate rate of rotation; in this case, the flattening is frequently due to the pitching moment produced by inertia forces;

III. as a consequence of flattening out, no matter how the model had been launched; in this case, the flattening often is rapid and mainly is due to an aerodynamic moment.

We then made an attempt to interpret the data. In the case I, one can conclude that, if the pilot keeps his controls in the same positions as those of the model from the very beginning of his spin, he will never reach the flat stationary spin obtained in the wind tunnel. Conversely, if by some means or other the pilot has reached a flat spin, he can recover from the spin by setting the controls in these same positions. /3

In the case III, it can be concluded that the rapid and flat spin will be easily obtained in full-scale flight.

In the intermediate case II, allowance must be made for the maximum modulus of longitudinal trim, beyond which the spin does not become established, for the rate of entry into spin, and for the spins obtained with other settings of the control surfaces. The rate of establishment of spin is highly important since it indicates the time available to the pilot for counteracting the spin as well as the number of turns to be made in flight in order to reach a stabilized spin.

In these cases of rapid and flat spins, for a given configuration of the controls, we thus define the following:

stabilized spin;
range of longitudinal trim, starting from which spin can be obtained;
minimum rate of rotation to be imparted at the beginning so as to obtain a spin;
time required for flattening out on the one hand and for obtaining maximum rate of rotation on the other.

With consideration of all these elements, we drew general conclusions for a given aircraft. Based on these conclusions, comparisons were conducted with flight tests. Such a comparison usually should cover only the phase of establishment of spin; specifically, caution must be exerted not to assume absence of agreement merely because, after several turns in flight, rapid and flat stationary spin has not been reached.

b) Agitated Spin

Let us now talk of the possible agitations during a spin. Such fluctuations are a frequent occurrence and thus also necessitate interpretation of model tests. In the wind tunnel, it is readily possible to launch the model in such a manner that the motion is of the purest possible type at the beginning. From then on, the evolution of motion can be closely followed: Such motion will either remain calm or soon will become subject to agitations. These may become stationary or else divergent in which case the spin proper will end. Here, /4
we again must introduce the conditions under which the full-scale aircraft enters a spin: In all cases, during the incipient spin, considerable vibratory stresses exist. Thus, if such vibrations appear almost immediately in the wind tunnel, it must be concluded that the spin of the full-scale aircraft will always be agitated. If, conversely, the agitated spin is established slowly or if it damps spontaneously, it is just as possible to encounter a calm or an agitated spin in actual flight. Still another case exists which must not be neglected: To obtain a calm spin of the model it is absolutely necessary to launch the model in completely calm regime since even the slightest agitation would prevent establishment of a calm spin; here, it must be concluded that a calm spin is impossible in actual flight. This latter case must be supplemented by certain rapid and flat spins which can be obtained only by launching the model in a steeper dive, at a lower speed, and with some agitation; in that case, the increasing vibrations do not permit establishment of a rapid and flat spin in the wind tunnel; this means that, in actual flight, this type of spin would be highly improbable.

With respect to such agitations, we avoid purposely to use the designation "recovery from spin" for any termination of spin as a consequence of agitations. In fact, certain attitudes reached are little conducive to regaining control of the aircraft: Either the agitations degenerate into an autorotation or else they become violent, affecting the pilot and causing him to become disoriented.

Lateral vibrations frequently were almost the only type to reach high amplitudes; however, in more modern aircraft we noted a tendency to strong vibrations of the longitudinal trim, which frequently diverged rapidly and resulted in passage through vertical attitudes, which does not always lead to recovery from spin.

Certain such agitations diverge so rapidly that one could conclude that, under certain configurations, the aircraft could make only extremely short evolutions which would be difficult to compare with true spins.

c) Recovery from Spin /5

Let us now discuss the manner in which certain characteristics of spin recovery can be appreciated. Here again, it is a question of making allowance not only for the geometry of the movements but also for the rate at which the latter take place.

With respect to recovery from spins reaching almost vertical attitudes, the problem is mainly one of the variation in speed of rotation. During recovery from a spin, it is hoped simultaneously that the mean incidence of the aircraft will decrease and that the rotation will stop. However, the pilot is made aware of the end of a spin more by the stoppage of rotation than by the decrease in angle of attack. For numerous aircraft of recent design, recovery from a spin can be obtained only if the ailerons are deflected in direction of the spin. If, during recovery obtained by this maneuver, the aircraft goes into a dive it happens often that, with the ailerons returning to their normal efficiency, a roll about the vertical axis takes place at the end of evolution which starts before the spin rotation has been stopped. In that case, the pilot will have some difficulty to define the exact moment at which the spin is terminated, i.e., the motion involved here no longer meets the definitions given by A.Martinot-Lagarde in Section 1.1 of his paper. The only means the pilot has available for realizing that he no longer is in a spin is the increase in his velocity of translation; this means that he has lost time, i.e., that he cannot obtain restoration at the earliest possible moment. Thus, although wind-tunnel tests show spin recovery passing over into a vertical roll within n turns, one must add to this the time necessary for the pilot to become aware of the change in the type of rotation. For this reason, we are classifying the vertical recovery from a spin with rotation into two groups: those during which the rotation actually stops or at least slows down distinctly and those in which the rotation retains the same value practically throughout. With respect to the former groups, the interval of time during which deceleration occurs must be noted; the latter groups must be avoided as far as possible.

Nevertheless, stoppage of rotation must not be looked for at all cost. To demonstrate this point, we will give certain instances with reference to spin recovery which we will denote as "lateral". During these types of spin, the longitudinal trim varies little. It is specifically on recovery from lateral spins that the most distinct stoppage of rotation is obtained; however, at the same time that this stoppage is obtained, the attitude and velocity of translation of the aircraft may develop in different fashions. If, at the same /6
time as stoppage of rotation takes place, the leading wing is raised and if an increasing velocity parallel to the longitudinal axis of the aircraft is superposed to the velocity of initial descent, then the recovery can be considered as satisfactory. Conversely, if the wing span remains horizontal and if the speed of the aircraft itself changes little, the conditions are propitious for a new start of spin which usually takes place in the inverse direction since the control-surface setting had been favorable for this. Here again, the time

element intervenes; one must know whether the pilot, as is necessary, can appreciate the end of his spin before reversal of the spin into an inverted spin has started. In the case of lateral recoveries, one must check whether the model has a tendency to diverge in an inverse direction and the rate at which the inverted spin becomes established. It should be mentioned that, during lateral recoveries with increase in speed, the model will at times start a slight rotation in the opposite direction; in this case, we conclude this to be a correct recovery, thinking that - if the increase in speed is sufficiently distinct - a new spin cannot take place.

2. Full-Scale Flight Tests /7

The notes given here with respect to actual flight tests are not as complete as could be furnished by the C.E.V. since the IMF (Fluid Mechanics Institute) of Lille does not have its own flight testing service. Nevertheless, discussions with the pilots assisting in various wind-tunnel tests and contacts with the C.E.V. as well as the testing service of various aircraft construction companies have permitted certain conclusions, of a more qualitative than quantitative nature.

Among the tests made after our 1954 paper had been published, we failed to record divergences of some importance, either in spin attitudes or in the characteristics of spin recovery.

It should be mentioned that the start of spin, subsequent to takeoffs at low velocity, generally are not abrupt; in some cases, it is even difficult to induce spin by this particular method. Conversely, if the takeoff is done with a certain load factor, the start of spin may be extremely violent and the evolutions are difficult to interpret by the pilot who, misled, becomes rapidly disoriented. Restitution of these violent starts is difficult since it requires measuring a large number of parameters. From this, one can draw the conclusion that an aircraft, taking off with a load factor, will then more readily go into a spin the more the disoriented pilot is unable to counteract the motion from its very beginning.

In its incipient phase, the spin undergoes oscillations due to the oblique direction of the mean path of the center of gravity. These oscillations are of a highly characteristic type, easy to recognize: Their period is the turn itself and they will damp if the final spin is calm. Among the full-scale spins comparable to our wind tunnel tests, we observed excellent agreement between calm and agitated type of spin, deducting the incipient agitations. One particular aircraft, for which the model spin had been of the agitated type and finally degenerated into an autorotation, actually performed a spin of this type.

Until now, we have no data on flight tests in which the spin had been continued until a rapid and flat spin set in. Incidentally, this is as it should be since otherwise the accelerations suffered by the pilot would prevent him /8
from taking any action.

For agreement between wind tunnel and flight tests, with respect to the control surface effect, it is of interest to differentiate between direction of action and modulus of this action. A pilot, so long as he knows in which direction he is turning, always is able to set the controls in the prescribed direction. This is not so for the modulus of his action. In this regard, it is quite interesting to verify, exclusively from the impressions gained by the pilot, that the direction of action defined in the wind tunnel always is encountered in actual flight. So far as the necessary setting of the controls is concerned, it seems that the action of the pilot should be simplified so as to make it more accurate. For this, it is preferable to give instructions without strict definition: each control surface fully deflected in one or the other direction or, if necessary, controls free if control surface is not reversible, with the control column well balanced and centered at neutral. In that case, the pilot must be given information on the type of recovery he will encounter and the parameters he must observe to know when to stop applying the command. This is even more necessary since with fully deflected control surfaces, reversal of direction, passage into vertical roll, or abrupt change to inverted flight are more likely to be encountered. We should mention here the case of spin recovery obtained in the wind tunnel by a progressive transformation of the spin into a vertical roll, with the ailerons low. In the full-scale aircraft, the same type of recovery was obtained. A pilot, in making a check flight, had received the signals referring to the control surfaces for spin recovery; he applied the commands properly and waited for the rotation to stop. Since this did not happen, he returned the ailerons to neutral in order to perform a different maneuver; at that very moment, the rotation stopped. The pilot concluded from this that the recovery commands to be applied were exactly the opposite of those worked out in the wind tunnel; however, the recordings made proved that the spin itself had been replaced by actual rolls. If the pilot had been advised beforehand of the type of recovery involved, he would not have expected his maneuver to produce a stoppage of rotation and would have judged the end of his spin from the airspeed indicator.

A final remark should be made with respect to flight tests, namely, that it is not always desirable to stop a spin from its inception. The maneuver /9 performed in that case, even if it would stop the incipient rotation, cannot be favorable to regaining control of the aircraft. It is well possible, and this has actually happened, to obtain a succession of alternate starts in one or the other direction, without the aircraft ever going into a regular dive. Conversely, if the spin, before starting a counteraction, were allowed to continue to a stabilized spin, one could then properly apply the controls for recovery thus obtaining a clean end of the motion.

3. General Studies /10

The prototypes constructed several years ago had the basic characteristic of great susceptibility for lateral vibration, thus attaining evolutions difficult to describe. In recent years, flat spins were performed with increasing frequency; some of these were slow and many reached very high rates of rotation. It should be noted that such spins were observed on Delta wings, on sweptback wings, and even on straight wings. Such flat spins are especially dangerous when accompanied by a high speed of rotation. The pilot, frequently sitting far forward of the center of gravity, is subjected to accelerations that may prevent him from executing maneuvers for spin recovery, seeing that such maneuvers must be applied over many turns before becoming truly effective. Here, a number of goals must be reached which are, in addition, closely interrelated:

reduction in maximum velocity of rotation of the spin, obtainable in flight;

reduction in the number of control-surface configurations, permitting rapid and flat spin in flight;

restriction in the range of longitudinal trim, subsequent to which the rapid and flat spin can become established.

It is well possible that the desired goals can be obtained without having been able to prevent all flat spins in the wind tunnel. In fact, in agreement with our above statements the final goal is not so much to attempt suppressing any flat spin in the wind tunnel as to prove by wind-tunnel tests that the aircraft would run little chance of going into such spins. Let us state that, for a large number of aircraft, the control surfaces in themselves are inadequate for reaching the desired goal.

We have tested air brakes, parachutes, auxiliary surfaces in the plane of symmetry at the tail, all of which furnished practically no result.

Conversely, the addition of "keelsons", i.e., fixed surfaces in the plane /11
of symmetry and below the fuselage nose, has always been found to be the most efficient means. By increasing the area of such keels, the following successive results are obtained: reduction in maximum velocity of rotation, reduction in possibilities of entering flat spins, suppression of any stationary spins. Such surfaces, naturally, are cumbersome and ugly. For this reason, attempts were made to replace these by movable surfaces; primarily, we thought of using aircraft flaps similar to the well-known cowcatcher on trains. During such tests, we made certain findings with respect to these "keels".

If they are mounted below a given surface such as below the relatively flat bottom of a fuselage, they will be more efficient than if placed at the fuselage nose.

A flap whose hinge is to the left has practically no effect on a left-hand spin whereas it is highly efficient for a right-hand spin.

Two parallel surfaces, arranged symmetrically with respect to the plane of symmetry of the aircraft and spaced quite closely, have less effect than a single such surface placed in the plane of symmetry.

These attempts at modifying existing spins and comparisons between spins of different aircraft have induced us to conclude that the shape of the transverse frame of the fuselage apparently has an important influence on the capability of a given aircraft to execute rapid and flat spins. We then undertook, on a Delta wing, a test with five long and heavy fuselages of differing frame designs, with the fuselages all being inscribed into one among them that had the configuration of a body of revolution. Thus, the frames represented ellipses with respect to the vertical axis on the horizontal axis 2, 4/3, 1, 3/4, and 1/2. These tests are still in progress and we only have the results for the vertically flattest fuselage A, for the round fuselage C, and for the horizontally flattest fuselage E. The fuselage A permits no stationary spin at all

and exhibits no tendency to spin flattening. The fuselage E leads to rapid flattening and to considerable increase in the rate of rotation; the control surfaces permit no reliable nor rapid recovery from spin. The intermediate fuselage C yielded intermediate results; this type permits flat spins of relatively high speed, and the control surfaces more or less efficiently counter- /12
act the spin.

Let us now discuss the place where, and the manner in which, the Reynolds number intervenes in these tests. Primarily, the effect of the Reynolds number consists in variously fixing the points of transition and of flow separation.

For the fuselage E, each frame can be compared to a thick wing profile having its chord parallel to the aircraft span; its angle of attack is very high, and the Reynolds number can have only a minor effect: The point of flow separation can be located only in the direct vicinity of the point of maximum curvature. It is exactly for fuselage configurations close to the latter that we have always encountered the largest number of rapid and flat stationary spins.

For the fuselage A, the frames can be compared to profiles which now have their chords in the plane of symmetry; here, the angle of attack is relatively low and the Reynolds number may have an effect. Neihouse mentioned that this effect consists in rendering the spin of the model more flat and more rapid than in full-scale flight. This would mean that the flat and rapid spins obtained on the model do not represent movements possible in the full-scale aircraft. However, it is exactly for fuselages resembling these particular designs that we never obtained rapid and flat spins. Thus, it seems that, if the Reynolds number has any influence at all, the action must be of a different type.

This leaves the discussion of the round fuselage C; there is no doubt that the Reynolds number will have the greatest effect on this particular configuration. The fuselage frames cannot be absolutely compared to a definite profile, and there exists no preferred point on which flow separation might take place. In fact, the separation of flow will have difficulty to become established at any one point. We mounted longitudinal fairings to various points of the wall of the fuselage nose C. Until now, the only effect was that, in certain positions, a distinct tendency to rapid and flat spin was observed. It should be mentioned that, in the fuselage A, we were able in this manner to obtain a considerable reduction in the damping due to the fuselage; finally, the effect of these fairings on the spin of the configuration E is always extremely low. It seems that the use of such devices is highly precarious. The phenomenon of spin is rarely permanent, so that the angles of attack continually change in time. With respect to a fuselage, having no preferred points for flow separation, it is certain that this point of flow separation shifts constantly. Fixing this /13
point artificially with respect to the model may introduce a source of errors.

It seems that the scale effect will always be low as long as the contours of the fuselage frames show excessive local variations in the radius of curvature below the maximum width of the frame.

To reduce the effect of the Reynolds number, the most obvious solution is an increase in scale of the model. It should be mentioned that a rather important parameter must be taken into consideration here: the critical Reynolds number R_c which characterizes the microturbulence of flow around the model. The lower this R_c, the smaller will be the scale effect. In a vertical wind tunnel, it is thus of interest to have a rather high microturbulence, without proof that this leads to a macroscopic turbulence. Models launched in a calm atmosphere will be in a flow of maximum R_c; to obtain the same scale effect, both in the wind tunnel or in the free atmosphere, the wind-tunnel models could thus be somewhat smaller.

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